

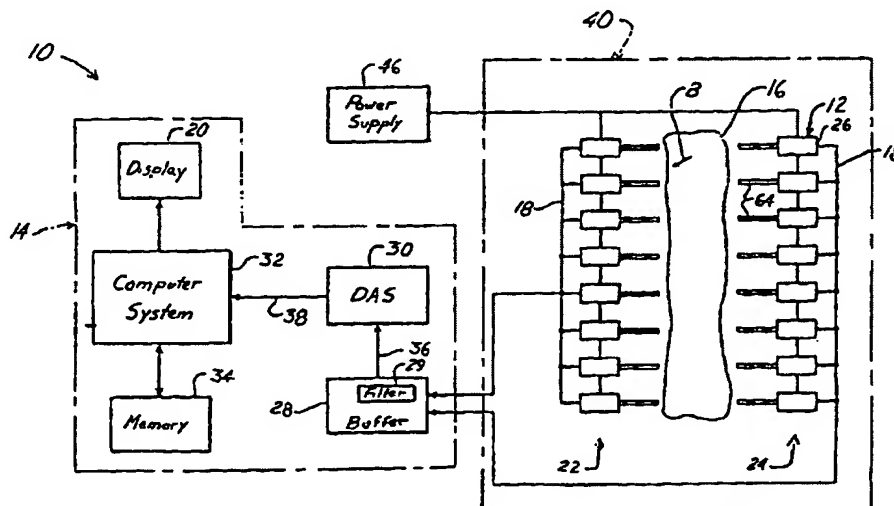


INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

Best Available Copy

(51) International Patent Classification 6 : G01R		A2	(11) International Publication Number: WO 97/50000
			(43) International Publication Date: 31 December 1997 (31.12.97)
(21) International Application Number: PCT/US97/10613 (22) International Filing Date: 13 June 1997 (13.06.97) (30) Priority Data: 60/019,928 14 June 1996 (14.06.96) US (71) Applicant (for all designated States except US): LOCKHEED MARTIN IDAHO TECHNOLOGIES COMPANY [US/US]; 2525 N. Fremont Avenue, P.O. Box 1625, Idaho Falls, ID 83415 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): RICE, Philip, M. [US/US]; 2760 Tipperary Lane, Idaho Falls, ID 83404 (US). MANHARDT, Joseph, M. [US/US]; 7102 77th Avenue, N.E., Marysville, WA 98270 (US). ROYBAL, Lyle, G. [US/US]; 635 Renny Avenue, Idaho Falls, ID 83401 (US). (74) Agent: KIRSCH, Alan, D.; Lockheed Martin Idaho Technologies Company, P.O. Box 1625, Idaho Falls, ID 83415-3899 (US).			(81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE, GH, HU, IL, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZW, ARIPO patent (GH, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). Published Without international search report and to be republished upon receipt of that report.

(54) Title: ADVANCED METAL DETECTION EQUIPMENT USING FLUXGATE MAGNETOMETERS



(57) Abstract

Advanced metal detection apparatus according to the present invention may comprise a plurality of magnetometers for sensing a magnetic field and for producing output data signals relating to the detected magnetic field. The magnetometers may be arranged along a first row and define a sensing area. A signal processing apparatus connected to each of said plurality of magnetometers is responsive to the output signals produced thereby and generates a human-readable display indicative of the presence of the ferromagnetic object within the sensing area.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece			TR	Turkey
BG	Bulgaria	HU	Hungary	ML	Mali	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MN	Mongolia	UA	Ukraine
BR	Brazil	IL	Israel	MR	Mauritania	UG	Uganda
BY	Belarus	IS	Iceland	MW	Malawi	US	United States of America
CA	Canada	IT	Italy	MX	Mexico	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NE	Niger	VN	Viet Nam
CG	Congo	KE	Kenya	NL	Netherlands	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NO	Norway	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	NZ	New Zealand		
CM	Cameroon			PL	Poland		
CN	China	KR	Republic of Korea	PT	Portugal		
CU	Cuba	KZ	Kazakhstan	RO	Romania		
CZ	Czech Republic	LC	Saint Lucia	RU	Russian Federation		
DE	Germany	LI	Liechtenstein	SD	Sudan		
DK	Denmark	LK	Sri Lanka	SE	Sweden		
EE	Estonia	LR	Liberia	SG	Singapore		

**ADVANCED METAL DETECTION EQUIPMENT USING
FLUXGATE MAGNETOMETERS**

REFERENCE TO CO-PENDING PROVISIONAL APPLICATION

Applicants hereby claim the benefit of an earlier filed co-pending provisional application, Application No. 60/019,928, filed on June 14, 1996.

CONTRACTUAL ORIGIN OF THE INVENTION

The United States Government has rights in this invention disclosed under contract number DE-AC07-76ID01570 between the U.S. Department of Energy and EG&G Idaho, Inc., now contract number DE-AC07-94ID13223 with Lockheed Idaho Technologies Company.

Field of Invention

This invention relates to metal detection apparatus in general and more specifically to a method and apparatus for detecting concealed weapons.

BACKGROUND OF THE INVENTION

Concealed weapons detection systems are used in a wide range of situations in order to provide added security against violent crimes. In addition to the well-known use of concealed weapons detection systems in public airports, such weapons detection systems are increasingly being used in court houses, schools and other public/governmental facilities that may be subject to threats or attacks by various members of the public.

One commonly used concealed weapons detection system is the electromagnetic (EM) induction system. Essentially, an EM induction system operates by periodically broadcasting an electromagnetic pulse or series of pulses, usually in the kilohertz range. It is believed that the transmitted electromagnetic pulse induces an electrical current or currents in electrically conductive objects contained within the sensing area. The induced electrical current

1 or currents create their own electromagnetic signals which are then
2 detected by a suitable detector associated with the weapons
3 detection system.

4 While EM induction systems of the type described above have
5 been used for decades as concealed weapons detection systems, they
6 are not without their problems. For example, such EM induction
7 systems are generally sensitive to the overall size, i.e., surface
8 area of the object, not its mass. Consequently, small, compact, but
9 massive objects, such as a small pistol, may not produce a
10 "signature" that is significantly larger than the signature produced
11 by a light weight object of the same size, such as keys or pocket
12 change. Another problem associated with EM induction systems is
13 related to the fact that EM systems are sensitive to electrically
14 conductive objects, regardless of whether they are magnetic or non-
15 magnetic. That is, EM systems tend to detect non-magnetic objects,
16 such as pocket change, just as easily as magnetic objects (e.g.,
17 weapons). Consequently, EM systems tend to be prone to false
18 alarms. In many circumstances, such false alarms need to be
19 resolved by scanning the suspect with a hand-held detector in order
20 to confirm or deny the presence of a dangerous weapon.

21 Accordingly, a need exists for an improved weapons detection
22 system that reduces or eliminates some of the shortcomings and
23 problems associated with conventional, EM-induction systems. For
24 example, such an improved weapons system should have improved
25 sensitivity and selectivity to reduce the occurrence of "false
26 alarms," i.e., the detection of metals and materials that are not
27 weapons. If the improvements in sensitivity and selectivity were
28 significant, such an improved weapons detection system could be more
29 safely monitored from a remote location. Indeed, several such
30 systems could be monitored from the same location. The detection
31 system or system could also be concealed, thereby reducing the
32 number of circumvention attempts that are typically associated with
33 more conspicuous detector systems. Additional advantages could be
34 realized if such a system would be reliable and relatively
35 inexpensive to implement and operate.

SUMMARY OF THE INVENTION

Advanced metal detection apparatus according to the present invention may comprise a plurality of magnetometers for sensing a magnetic field and for producing output data signals relating to the detected magnetic field. The magnetometers may be arranged along a first row and define a sensing area. A signal processing apparatus connected to each of said plurality of magnetometers is responsive to the output signals produced thereby and generates a human-readable display indicative of the presence of the ferromagnetic object within the sensing area.

BRIEF DESCRIPTION OF THE DRAWINGS

Illustrative and presently preferred embodiments of the invention are shown in the accompanying drawings in which:

Figure 1 is a block diagram of one embodiment of a system for detecting the presence of a ferromagnetic object according to the present invention showing the general arrangement of the sensor array and associated signal processing apparatus;

Figure 2 is a front view in elevation of a doorway sensor array with a portion of the wall covering removed to show the position and orientation of the two rows of magnetic sensors positioned on either side of the doorway;

Figure 3 is a perspective view of a fluxgate magnetic gradiometer that may be used with the present invention to sense magnetic field gradients;

Figure 4 is a flow diagram showing the data collection and classification process steps performed by the signal processing apparatus shown in Figure 1;

Figure 5 is a flow diagram showing the details of the sample and average sensor data step shown in Figure 4;

Figures 6A-F are graphical representations of magnetic field gradient vs. vertical position for an object having a dipole response characteristic;

Figures 7A-F are graphical representations of magnetic field gradient vs. vertical position for an object having a monopole response characteristic;

1 Figure 8 is a pictorial representation of another embodiment
2 of a display showing the approximate locations of ferromagnetic
3 objects detected on a person within the sensing area;

4 Figure 9 is a perspective view of a portable sensor array with
5 a portion of one of the panels broken away to show a magnetic
6 sensor;

7 Figure 10 is a front view in elevation of another embodiment
8 of a doorway sensor array with a portion of the wall covering
9 removed to show the position and orientation of the single row of
10 magnetic sensors; and

11 Figure 11 is a front view in elevation of a yet another
12 embodiment of a doorway sensor array comprising two rows of magnetic
13 sensors arranged above and below the doorway.

14 15 DETAILED DESCRIPTION OF THE INVENTION

16 One embodiment of the advanced metal detection apparatus 10
17 according to the present invention is shown in Figure 1 and may
18 comprise a sensor array 40 connected to a signal processing system
19 14. The sensor array 40 may comprise a plurality of magnetic
20 sensors or magnetometers 12, each of which is connected to a
21 suitable power supply 46 and to the signal processing system 14.
22 The sensors or magnetometers 12 sense changes or disturbances in an
23 ambient magnetic field B (e.g., the earth's magnetic field) caused
24 by the presence within the sensing area 16 of a ferromagnetic object
25 or objects (not shown). Each magnetometer 12 produces an output
26 signal 18 that is related to the detected changes in the magnetic
27 field B. The signal processing system 14 analyzes the output
28 signals 18 from the sensors or magnetometers 12 and produces a human
29 readable display 20 indicative of the location of the detected
30 ferromagnetic object or objects (not shown).

31 The magnetometers 12 that comprise the sensor array 40 may be
32 arranged in any of a wide variety of configurations to define a
33 sensing area 16 suitable for the detection of ferromagnetic objects
34 (not shown) with the desired degree of sensitivity. For example,
35 in the embodiments shown in Figures 1 and 2, the sensor array 40 may
36 comprise a plurality of magnetometers 12 arranged in two generally
37 vertically oriented rows; a first row 22 and a second row 24, with

1 each magnetometer 12 in each row 22, 24 being generally evenly
2 spaced from its neighbor. The rows 22, 24 are themselves aligned
3 so that the magnetometers 12 are positioned in generally opposed,
4 spaced-apart relation to one another, as best seen in Figure 1. In
5 the embodiment shown in Figure 2, the two rows 22, 24 of
6 magnetometers 12 are incorporated into a doorway 42 and define a
7 sensing area 16 that encompasses the opening 44 of the doorway 42.

8 The sensor array 40 may take on other configurations. For
9 example, the sensor array 40 need not be integrated into a doorway
10 and may instead comprise a portable sensor array 140, as best seen
11 in Figure 9. Portable sensor array 140 is similar to the sensor
12 array 40 and may comprise two free-standing panels 122, 124
13 positioned in opposed, spaced-apart relation. Each of the panels
14 122, 124 houses a plurality of magnetometers 112, generally in the
15 spaced-apart, opposed arrangement shown in Figures 1 and 2. Still
16 another embodiment of the sensor array 240 is shown in Figure 10 and
17 may comprise a single row 222 of sensors 212 incorporated into a
18 doorway 242. In yet another arrangement, the sensor array 340 may
19 comprise a horizontally oriented sensor array 340 that comprises a
20 plurality of sensors 312 arranged along an upper row 322 and a lower
21 row 324 positioned above and below a doorway 342. See Figure 11.

22 Regardless of the particular configuration of the sensor array
23 40, the magnetometers 12 are sensitive to disturbances in the
24 magnetic field **B** that may be caused by the presence within the
25 sensing area 16 of a ferromagnetic object or objects (not shown).
26 Actually, the magnetometers 12 only detect those portions of the
27 magnetic field **B** that actually impinge the magnetometers 12, but
28 most ferromagnetic objects of substantial mass and located within
29 the sensing area 16 will disturb the magnetic field **B** to a
30 sufficient degree so that the disturbance will be detected by at
31 least one of the magnetometers 12.

32 The magnetometers 12 may comprise any of a wide range of
33 devices for detecting changes in magnetic fields, as will be
34 described in greater detail below. In one preferred embodiment, the
35 magnetometers 12 may comprise fluxgate gradiometers 26 (Figure 3)
36 which, due to the horizontal orientation of their sensing rods 64,
37 sense changes in the horizontal gradient of the magnetic field **B**.

1 The signal processing system 14 is connected to the plurality
2 of magnetometers 12 and is sensitive to the output signals 18
3 produced by the magnetometers 12. The signal processing system 14
4 processes the output signals 18 and produces a human-readable output
5 on the display 20. In one embodiment, the human-readable output on
6 the display 20 may comprise a graphical representation of magnetic
7 field gradient vs. vertical position, as shown in Figures 6A-F.
8 Alternatively, the human-readable output on the display 20 may
9 provide a pictorial representation of the sensing area 16 with the
10 probable location or locations of the detected ferromagnetic object
11 or objects indicated by highlights 96. See Figure 8.

12 The signal processing system 14 may include a buffer system
13 28, a filter system 29, a data acquisition system (DAS) 30, and a
14 computer system 32. The computer system 32 may also include a
15 memory system 34 and a display system 20. The buffer system 28 is
16 connected to each of the magnetometers 12 and serves as an impedance
17 matching device to more closely match the output impedance of the
18 magnetometers 12 with the input impedance of the data acquisition
19 system (DAS) 30. The buffer system 28 receives the output signals
20 18 generated by the magnetometers 12 and produces a series of analog
21 output signals 36 that are received by the data acquisition system
22 30.

23 In one preferred embodiment, the buffer system 28 may include
24 a suitable electronic noise filter system 29 to remove ambient
25 magnetic "noise" of a periodic nature, e.g., the 50 or 60 Hz
26 magnetic fields created by a.c. power systems. Alternatively, the
27 signal processing system can remove or "filter" such periodic
28 magnetic noise signals by utilizing an "over-sampling" technique
29 that will be described in greater detail below.

30 The data acquisition system (DAS) 30 may comprise one or more
31 analog-to-digital (A/D) converter(s) (not shown) to convert the
32 analog signals 36 received from the buffer 28 into digital signals
33 38 suitable for use by the computer system 32. The data acquisition
34 system 30 may also be programmed to scan or sample the analog data
35 36 from the buffer system 28 (i.e., the output signals 18 from the
36 magnetometers 12) at specific sample rates and at specific sample
37 intervals, a process referred to herein as a "scanning function."

1 Accordingly, then, the digital signals 38 produced by the data
2 acquisition system represent a large number of brief "snap-shots"
3 of the output signals 18 from the magnetometers 12.

4 The computer system 32 receives the digital signals 38 from
5 the data acquisition system (DAS) 30, processes the data signals 38,
6 and ultimately produces a human-readable display 20 of the magnetic
7 field data obtained from the sensors array 40. In one embodiment,
8 the human-readable display 20 may comprise a graphical
9 representation of the magnetic field gradient ∇ vs. vertical
10 position. See, for example, Figures 6A-F. Another type of human-
11 readable display 20 may comprise a pictorial representation of the
12 sensing area 16 with the probable locations and relative sizes of
13 the detected ferromagnetic objects indicated by highlights 96. See
14 Figure 8.

15 The computer system 32 implements a data collection and
16 classification process 48 in order to produce the human-readable
17 display 20. Referring now specifically to Figure 4, the first step
18 in the data collection and classification process 48 is to determine
19 whether the signal processing system 14 is being operated in either
20 a "stand-by" mode or a "data collection" mode. If the signal
21 processing system 14 is being operated in the "stand-by" mode, no
22 data will be collected and the system 14 will continue to repeat
23 step 50 until the computer system 32 receives a command to enter the
24 "data collection" mode. Once such a command is received, the system
25 14 will switch to the "data collection" mode and proceed to step 52.
26 At this point, the system 14 may be operated in one of two "data
27 collection" modes: A "baseline data collection" mode or a
28 "surveillance data collection" mode.

29 The "baseline data collection" mode (steps 54 and 56) is used
30 to collect "baseline data." Essentially, the "baseline data" are
31 representative of the ambient magnetic field B, i.e., when no
32 ferromagnetic objects are located in the sensing area 16. When the
33 system 14 is operated in the "baseline data collection" mode, data
34 from the magnetometers 12 is collected, averaged, and stored as
35 "baseline data." Generally speaking, if the detection apparatus 10
36 is being operated for the first time or if it is being operated at
37 a new site or location, it will usually be desirable to first

1 operate the system 14 in the "baseline data collection" mode.
2 Alternatively, the system 14 may be operated in the "baseline data
3 collection" mode at periodic intervals (e.g., every ten (10) minutes
4 or so) to ensure that the "baseline data" more accurately reflects
5 the current characteristics of the ambient magnetic field B.

6 Once the "baseline data" have been collected and stored, the
7 system 14 may be operated in the normal or "surveillance data
8 collection" mode (steps 54-62). In the normal or "surveillance data
9 collection mode," the output data signals 18 from the magnetometers
10 12 are sampled by the data acquisition system 30 and fed into the
11 computer system 32. These data are referred to herein as
12 "surveillance data." The "surveillance data" may then processed to
13 determine whether ferromagnetic objects (not shown) are present
14 within the sensing area 16.

15 As a first step 58 in processing the "surveillance data," the
16 computer system 32 first subtracts the "baseline data" from the
17 "surveillance data" to produce "nulled" or "filtered surveillance
18 data," i.e., data from which the signature of the ambient magnetic
19 field B has been removed. The computer system 32 may then display
20 the "nulled" or "filtered surveillance data" on the display 20. In
21 one preferred embodiment, the "nulled" or "filtered surveillance
22 data" may be displayed in the form of magnetic field gradient ∇ vs.
23 vertical position, as best seen in Figures 6A-F.

24 In another embodiment, the computer system 32 may further
25 examine the "nulled" or "filtered surveillance data" in step 60 to
26 determine whether any magnetic anomalies are present that might be
27 indicative of the presence of a ferromagnetic object within the
28 sensing area 16. The resulting data are referred to herein as
29 "classified data." The computer system 32 then performs step 62 to
30 display the "classified data" on the display system 20 in a
31 convenient human readable form. See Figure 8. Depending on the
32 degree of analysis performed by the computer system 32, the computer
33 system 32 also may be programmed to actuate a visual or aural alarm
34 upon the detection of a predetermined quantity of ferromagnetic
35 material, i.e., material which may be indicative of the presence of
36 a weapon. Alternatively, the display 20 could flash a warning

1 signal 95, so that the operator (not shown) could take appropriate
2 security measures.

3 A significant advantage of the advanced metal detection
4 apparatus 10 according to the present invention is that it is
5 generally more discriminating than conventional EM induction
6 detectors. That is, since the metal detector 10 is generally
7 sensitive to ferromagnetic materials while being generally
8 insensitive to non-ferromagnetic materials, the system 10
9 significantly reduces the frequency of false alarms that may be
10 caused by the detection of non-ferromagnetic materials, such as
11 pocket change, keys, jewelry, etc. When an alarm condition is
12 detected, it is usually the result of the detection of a threshold
13 mass (and a corresponding suspicious location) of ferromagnetic
14 material. Therefore, the present invention substantially increases
15 the chances that the detected object is, indeed, of relevance.

16 The greater discrimination associated with the metal detector
17 10 of the present invention could allow several detectors to be
18 monitored from a single station, thereby reducing the number of
19 attendants required to monitor the system and generally lowering
20 operating costs. Another advantage of the invention is that it can
21 be readily concealed within a wall or doorway. Consequently, if no
22 attendants are present at or near the actual detector location, the
23 system may be less prone to circumvention attempts since persons
24 will not be aware that they are under surveillance by the detection
25 system 10.

26 Still other advantages are associated with the invention. For
27 example, the fluxgate gradiometers 26 that may be used as the
28 sensing magnetometers 12 are relatively inexpensive and reliable,
29 thereby reducing overall cost of the detection system and reducing
30 the down-time that may be required for repairs. The signal
31 processing system 14, being based on a general purpose programmable
32 computer, can be readily programmed to present the data in any of
33 a wide-range of human-readable forms. Improved detection or display
34 capabilities can also be readily incorporated into the detector
35 apparatus 10 by simply re-programming the computer system 32.

36 Having briefly described the advanced metal detection
37 apparatus 10 according to the present invention, as well as some of

1 its more significant features and advantages, the various
2 embodiments of the advanced metal detection apparatus will now be
3 described in detail.

4 Referring back now to Figure 1, one embodiment of the advanced
5 metal detection apparatus 10 may comprise a sensor array 40 that is
6 connected to a signal processing system 14. The sensor array 40 may
7 comprise a plurality of magnetic sensors or magnetometers 12 that
8 are sensitive to changes produced in an ambient magnetic field B
9 (e.g., the earth's magnetic field) by the presence generally within
10 the sensing area 16 of a ferromagnetic object or objects (not
11 shown). As used herein, the term "ferromagnetic" refers to those
12 metals, alloys, and compounds of the transition (iron group) rare-
13 earth and actinide elements in which the internal magnetic moments
14 spontaneously organize in a common direction, giving rise to a
15 magnetic permeability considerably greater than that of vacuum and
16 to magnetic hysteresis. Ferromagnetic materials may include,
17 without limitation, iron, nickel, cobalt, and various alloys
18 thereof.

19 The sensor array 40 may take on any of a wide range of
20 configurations depending on the desired sensitivity and detection
21 characteristics of the detector apparatus 10 as well as on the type
22 of installation. For example, in the embodiment shown in Figures
23 1 and 2 the magnetometers 12 comprising the sensor array 40 may be
24 arranged in spaced-apart relation so that they form two rows, a
25 first row 22 and a second row 24. Each magnetometer 12 in each row,
26 e.g., 22, 24, may be generally evenly spaced from its neighbor,
27 while the rows 22, 24 themselves may be arranged so that the
28 magnetometers 12 are positioned in generally aligned, but opposed,
29 spaced-apart relation on either side of the sensing area 16. See
30 Figure 1. Each magnetometer 12 in the array 40 may be electrically
31 connected to a suitable power supply 46 and to the signal processing
32 system 14 via any convenient means, such as copper wire, etc. (not
33 shown).

34 The arrangement of the two rows 22, 24 of magnetometers 12 is
35 such that a sensing area 16 is defined generally between the rows
36 22, 24 of magnetometers 12, as best seen in Figures 1 and 2. A
37 ferromagnetic object (not shown) having sufficient mass and located

1 within the sensing area 16 will create a disturbance in the ambient
2 magnetic field B that may be detected by one or more of the
3 magnetometers 12. As will be described in greater detail below, the
4 ability to detect disturbances in the magnetic field B caused by the
5 presence of ferromagnetic material (not shown) within the sensing
6 area 16 depends to a large extent on the type and sensitivity of the
7 magnetometers 12 as well as on the spacing between the
8 magnetometers, both within a given row, e.g., row 22, and between
9 the rows 22, 24, themselves.

10 For example, the sensor array 40 shown in Figures 1 and 2
11 comprises two rows 22, 24 of magnetometers 12 and provides generally
12 superior detection capability and sensitivity compared with the
13 sensor array 240 shown in Figure 10 that comprises only a single row
14 222 of magnetometers 212. Specifically, the sensor array 240
15 suffers from generally decreased sensitivity with regard to
16 ferromagnetic objects that may be located at the extreme right-hand
17 side 241 of the doorway 242, since all of the detectors 212 are
18 located on the left side 243 of doorway 242.

19 The magnetometers 12 may comprise any of a wide range of
20 devices capable of detecting magnetic fields, such as, for example,
21 cesium vapor and proton precession magnetometers. However, in one
22 preferred embodiment each magnetometer 12 comprises a fluxgate
23 gradiometer 26, as best seen in Figure 3. Essentially, a fluxgate
24 gradiometer is a type of magnetometer that is sensitive to changes
25 in the gradient of a magnetic field B . As used herein, the term
26 "gradient" defines a vector quantity obtained from the magnetic
27 field B whose components are the partial derivatives of B such that
28 the gradient of the magnetic field B is the maximum rate of change
29 of B in a given direction.

30 Still referring to Figure 3, each fluxgate gradiometer 26 may
31 comprise two separate fluxgate magnetometers (not shown) mounted
32 within the sensing rod 64 at opposite ends 66, 68 thereof. Each
33 fluxgate magnetometer (not shown) is connected to a suitable
34 electronic control system (not shown) contained within the housing
35 70. Since the two fluxgate magnetometers (not shown) are positioned
36 in spaced-apart relation within the sensing rod 64 (i.e., at or near
37 the opposite ends 66, 68 of the sensing rod 64) the gradient of the

1 magnetic field **B** along the direction of the rod 64 may be determined
2 by comparing the signals from the two magnetometers. The electronic
3 control system (not shown) contained within the housing 70 compares
4 the signals from the two magnetometers and produces the output
5 signal 18 that is related to the gradient of the detected magnetic
6 field **B**.

7 As mentioned above, each fluxgate gradiometer 26 of the type
8 shown in Figure 3 is generally sensitive to changes in the magnetic
9 field gradient in the direction of orientation of the sensing rod
10 64. Accordingly, for the case where the fluxgate gradiometers 26
11 are mounted so that their respective sensing rods 64 are oriented
12 horizontally, (e.g., Figures 1, 2, 9, and 10) the gradiometers 26
13 are sensitive to variations in the horizontal gradient of the
14 magnetic field **B**. If, on the other hand, the gradiometers 26 are
15 mounted so that their respective sensing rods are oriented
16 vertically (e.g., Figure 11), then the gradiometers will be
17 sensitive to variations in the vertical gradient of the magnetic
18 field **B**.

19 In one preferred embodiment, each fluxgate gradiometer 26 may
20 comprise a Model No. GA-72Cd fluxgate gradiometer manufactured by
21 the Schonstedt Company of Reston, VA, although other brands and/or
22 types of magnetometers may be used without departing from the scope
23 of the present invention.

24 In one embodiment, the sensor array 40 may be concealed within
25 a doorway 42. Referring now to Figure 2, the concealed array 40 may
26 comprise a plurality of magnetic sensors or magnetometers 12 mounted
27 on either side of the opening 44 of the doorway 42. The sensors 12
28 may be mounted by any convenient means so that they are arranged in
29 a first generally vertically oriented row 22 and a second generally
30 vertically oriented row 24 on either side of the opening 44 of
31 doorway 42. The two rows 22, 24 of magnetometers 12 therefore
32 define a sensing area 16 that is generally contained within the
33 opening 44 of doorway 42. So arranged, the magnetometers 12 are
34 capable of detecting changes in the horizontal gradient of the
35 ambient magnetic field **B** caused by the presence generally within the
36 sensing area 16 of a ferromagnetic object or objects (not shown).
37 The magnetometers or sensors 12 used in the concealed sensor array

1 40 may comprise fluxgate gradiometers 26, as best seen in Figure 3
2 and as described above.

3 Since the sensors 12 are sensitive to magnetic disturbances
4 caused by the presence of ferromagnetic materials, the doorway 42
5 and surrounding materials should be made from non-ferromagnetic
6 materials, e.g., wood, aluminum, etc., so as not to adversely affect
7 the sensitivity and performance of the detection apparatus 10. For
8 example, in the embodiment shown in Figure 2, the sensor array 40
9 may be integrated into a conventional wood-framed wall section 72
10 comprising a plurality of 2x4 wooden studs 74 covered with a
11 conventional wall material 76, such as "dry wall" or "gypsum board."
12 The various components of the wall section 72 within the immediate
13 vicinity of the magnetometers 12 should be constructed from non-
14 ferromagnetic materials and fasteners, such as, for example,
15 aluminum or brass nails and/or wood dowel pins. The power supply
16 and output signal wires may be routed to the magnetometers 12 within
17 a conduit 78 made from a non-ferromagnetic material, such as
18 aluminum or plastic.

19 While any number of magnetometers 12 may be incorporated into
20 the sensor array 40 integrated within the doorway 42, in one
21 preferred embodiment the concealed sensor array 40 comprises eight
22 (8) fluxgate gradiometers 26 per row 22, 24 for a total of sixteen
23 (16) gradiometers 26. Assuming the doorway 42 is of standard height
24 (i.e., 80 inches) and width (i.e., 30-36 inches), the vertical
25 distance separating each gradiometer 26 in each row may be about
26 eight to ten (8-10) inches. Likewise, the horizontal distance
27 between the two rows 22, 24 may be in the range of about 3-4 feet
28 or so.

29 As was briefly mentioned above, the sensor array 40 comprising
30 two rows 22, 24 of magnetometers 12 (Figures 1 and 2) generally
31 provides superior detection capability due to the fact that the rows
32 22, 24 are positioned adjacent the right-hand and left-hand sides
33 41, 43 of the doorway 42. Accordingly, the sensor array 40 will be
34 more likely to detect the presence of a ferromagnetic object even
35 though it may be located at or near the extreme right-hand or left-
36 hand sides 41, 43.

1 The signal processing system 14 may be located at a remote
2 location from the concealed sensor array 40 thereby allowing for the
3 discrete scanning of persons passing through the doorway 42.
4 Alternatively, however, the signal processing system 14 and/or
5 associated display 20 may be located in plain view adjacent the
6 doorway 42 if so desired. In still another embodiment, the signal
7 processing system 14 may be located in the general area of the
8 sensor array 40 and may be connected to a remote computer and
9 display system (not shown) via an Ethernet or similar data link.
10 In such an embodiment, the data from the sensors 12 may be collected
11 and processed by the signal processing system 14 according to the
12 processes described below. Then, the processed data may be sent to
13 the remote computer and display system (not shown) over the data
14 link.

15 Regardless of the particular location of the signal processing
16 system 14 (i.e., adjacent to or remote from the sensor array 40),
17 the signal processing system 14 collects the output data signals 18
18 from the sensor array 40, analyzes the data and presents them in a
19 human readable form on the display 20, as was briefly described
20 above. The attendant (not shown) may then evaluate the need to take
21 further security measures.

22 Referring back again to Figure 1, the signal processing system
23 14 may, in one preferred embodiment, comprise a buffer system 28,
24 a filter system 29, a data acquisition system (DAS) 30, and a
25 computer system 32. The computer system 32 may also include a
26 memory system 34 and a display system 20. The buffer system 28 is
27 connected between the sensors 12 and the DAS 30. The buffer system
28 28 receives the output signals 18 from the sensors 12 and produces
29 output signals 36 for the DAS 30 which are essentially equivalent
30 to the output signals 18 (i.e., the signals contain the same basic
31 information relating to the magnetic field B). The buffer system
32 28 essentially acts as an impedance matching device to more closely
33 match the output impedance characteristics of the magnetometers 12
34 with the input impedance characteristics of the data acquisition
35 system 30 to ensure accurate response. Accordingly, a buffer
36 system, such as buffer 28, may or may not be required depending on

1 the particular type of magnetometers 12 and data acquisition system
2 30 used in a specific application.

3 In one preferred embodiment, the buffer system 28 includes an
4 electronic filter circuit 29 to remove periodic noise signals
5 created by a.c. power systems that may be in close proximity to the
6 system 10. For example, a prominent source of magnetic "noise" in
7 commercial buildings results from the large number of a.c. powered
8 electrical equipment and devices that are usually associated with
9 such buildings. The a.c. current used by such equipment and devices
10 usually induces (i.e., creates) ambient magnetic fields that
11 fluctuate at the same frequency as the a.c. current (e.g., 50 or 60
12 Hz). Since the strength of such induced magnetic fields may be of
13 the same order of magnitude as the magnetic field being sensed by
14 the magnetometers 12, it is important to minimize the effect of such
15 induced magnetic fields.

16 One method for reducing the effects of such induced magnetic
17 fields is to utilize a filter 29. Essentially, the filter 29 may
18 comprise a notch filter (band rejection filter) that blocks signals
19 having the same frequency as the associated a.c. power systems
20 (e.g., 50 or 60 Hz). However, since such notch or band rejection
21 filters are well-known in the art and could be easily provided by
22 persons having ordinary skill in the art, the details of the
23 particular notch filter 29 incorporated into the buffer system 28
24 will not be described further.

25 The data acquisition system (DAS) 30 performs a data
26 collection or scanning function by scanning the analog output
27 signals 36 from the buffer 28, which are essentially identical to
28 the output signals 18 from the various sensors 12. The data
29 acquisition system (DAS) 30 then converts the scanned analog signals
30 36 into digital signals 38 suitable for processing by the computer
31 system 32. In one preferred embodiment, the data acquisition system
32 30 scans all of the sensors 12 in the array 40 nearly
33 simultaneously, so that the scanned data essentially represents a
34 single "snap shot" of the magnetic field characteristics at a
35 particular instant. The entire array 40 is then scanned at a lower
36 frequency to determine changes in the magnetic field over time.
37 While many different sampling rates may be used, in one preferred

embodiment, each magnetometer 12 in the array is sampled at a frequency of about 100 kHz. This high sampling frequency ensures that the time period between the sampling of two sensors is very short, in this case about 10 μ sec. Therefore, an array 40 containing 16 sensors can be sampled in about 160 μ sec. The frequency at which the entire array 40 is sampled is considerably lower, being about 1kHz. That is, the entire array 40 is sampled about 1000 times per second.

The buffer system 28 and data acquisition system 30 may comprise any of a wide-variety of systems suitable for performing the functions of each respective device, and the present invention should not be regarded as limited to any particular device or system. However, by way of example, the buffer system 28 used in one preferred embodiment may comprise a plurality of high impedance buffer cards manufactured by IOtech, Inc., of Cleveland, OH 44146 and identified as model no. DBK-8. Since each buffer card only accommodates 8 channels, a sufficient number of cards must be provided to accommodate at least the number of sensors 12 (thus data channels) being used for a specific installation. The data acquisition system 30 used in one preferred embodiment may comprise a model no. DAQbook 216 also manufactured by IOtech, Inc., of Cleveland, OH. The basic DAQbook 216 comprises a single analog-to-digital (A/D) converter with a standard configuration of 16 data channels. Each data channel is accessed by a high speed multiplexer (not shown). The number of data channels can be expanded up to 256 channels, which would be sufficient to allow several separate sensor arrays, e.g., sensor array 40, to be connected to a single data acquisition system 30.

As was described above, the data acquisition system (DAS) 30 performs the scanning function required to collect or sample the analog output signals 36 (i.e., output signals 18) received from the array 40 of magnetometers 12. While any of a wide range of sampling frequencies may be used, it may be desirable to implement an "over-sampling" process to minimize the effect of periodic magnetic field fluctuations, such as those caused by a.c. power systems. The use of such an "over-sampling" process is particularly advantageous if a separate notch filter 29 is not used. However, such an "over-

1 sampling" process may be used even if the system utilizes a separate
2 notch filter 29.

3 The "over-sampling" technique or process utilized in the
4 present invention provides another method for reducing the effects
5 of periodic magnetic field fluctuations, such as those induced by
6 a.c. power systems. The "over-sampling" process works by collecting
7 or sampling the output signals 18 in such a way so that they include
8 several different data points, preferably over several periods of
9 the known alternating cycle. The data points collected by the
10 "over-sampling" process are then averaged to produce a mean data
11 point representative of the sampled magnetic field.

12 By way of example, in one preferred embodiment of the
13 detection system 10 that operates in buildings containing 60 Hz
14 alternating current, the entire array 40 is sampled at a frequency
15 of about 1000 Hz, i.e., once every millisecond (msec). This
16 sampling frequency effectively provides 17 samples per sensor 12 per
17 60Hz a.c. cycle. While this may be a sufficient number of samples
18 for some applications, it is preferable to collect samples over
19 several a.c. cycles. A "sample group" as used herein refers to the
20 number of data points collected over a predetermined number of a.c.
21 cycles. We have discovered that sampling the data over at least
22 three (3) a.c. cycles provides good results. Therefore, in one
23 embodiment, the sample group for each sensor comprises fifty-one
24 (51) samples or data points, which corresponds to a time interval
25 of about 50 msec or about 3 60 Hz cycles. The data points for each
26 sample group are then added together and the sum divided by the
27 total number of samples in the sample group to yield an average
28 value for that particular sample group for the corresponding sensor
29 or magnetometer 12.

30 It should be understood that the particular number of samples
31 per sample group is not particularly critical, and a sample group
32 could comprise any of a wide range of individual samples (i.e., data
33 points), as would be obvious to persons having ordinary skill in the
34 art. Therefore, the present invention should not be regarded as
35 limited to only those configurations comprising 51 samples per
36 sample group.

1 The computer system 32 may comprise a general purpose
2 programmable computer suitable for controlling the data acquisition
3 system 30 and for performing the necessary data processing steps at
4 a speed sufficient to provide the desired degree of performance.
5 In one preferred embodiment, the computer system 32 may comprise a
6 standard computer card or board (e.g., a standard PC-104 form factor
7 card), of the type that are readily available and commonly used in
8 industrial applications. In another embodiment, the computer
9 system 32 may comprise a personal computer (PC) (e.g., a "notebook"
10 or "desk top" computer) of the type that is readily commercially
11 available. The computer system 32 may be mounted in any convenient
12 housing or structure (not shown) and may be located with the sensor
13 array 40. Alternatively, the computer system 32 may be located at
14 a remote position from the sensor array 40. If the computer system
15 32 is located with the sensor array 40 and a remote display is
16 desired, then the computer system 32 may be connected to a suitable
17 remote computer and display system (not shown) via a suitable data
18 link (e.g., Ethernet).

19 The computer system 32 may be programmed to operate the data
20 acquisition system 30 and to process and display the collected data
21 in a human-readable form on the display device 20. The display
22 device 20 may comprise a CRT or LCD display. The program may be
23 written in any of a number of languages (e.g., C++) and/or with any
24 number of programming aids or virtual instruments (e.g., Labview®
25 for Windows®) suitable for the intended application.

26 The details of the data collection and classification process
27 48 performed by the computer system 32 are best seen in Figures 4
28 and 5. The first step in the process 48 is step 50 wherein the
29 computer system 32 continually checks to determine whether it is
30 operating in a "stand-by" mode or a "data collection" mode. If the
31 system 14 is operating in the "stand-by" mode, then no data are
32 collected and the computer system 32 awaits a command instructing
33 it to enter the "data collection" mode. Once the computer system
34 32 is instructed to collect data from the sensors or magnetometers
35 12, the process proceeds to step 52. In one embodiment, the
36 selection of the mode of operation of the computer system 32 may be
37 accomplished by programming the computer system 32 to display a

1 message on the display system 20 instructing the attendant (not
2 shown) to press a key or "click" an icon to switch the computer
3 system 32 between the "stand-by" mode and the "data collection"
4 mode. However, since such processes for initiating program
5 sequences in response to user commands are well-known and would be
6 obvious to persons having ordinary skill in the art, the particular
7 program sequence for selecting between the "stand-by" mode and "data
8 collection" mode will not be described in further detail.

9 Step 52 "sample and average sensor data" comprises a plurality
10 of steps as set forth in Figure 5. Basically, step 52 initiates the
11 data collection (i.e., sampling) process by the data acquisition
12 system 30. Referring now to Figure 5, the first step 80 in the
13 process 52 is to scan the sensors 12 and collect data from the
14 output signals 18 received from the sensors 12. If a buffer system
15 28 is required, then the data acquisition system will sample the
16 analog signals 36 received from the buffer 28. See Figure 1.

17 As was described above, a number of samples or "snap shots"
18 are taken from each sensor 12, with each sample representing the
19 magnetic field gradient at a particular moment in time. For
20 example, in one preferred embodiment, the various sensors 12 in the
21 array 40 are sampled nearly simultaneously, e.g., at a frequency of
22 about 100 kHz (i.e., about 10 μ sec time between each sensor). The
23 entire array 40 is then sampled at a frequency of about 1000 Hz or
24 about once every msec. If the "over-sampling" process is used, then
25 a sufficient number of samples will be collected so that the samples
26 span a desired number of a.c. cycles. In one preferred embodiment,
27 51 samples will be collected for each sensor 12 (i.e., a sample
28 group). That is, the sample group for each sensor 12 will encompass
29 a time period extending over about three (3) 60 Hz a.c. cycles
30 (i.e., 50 msec).

31 Once the required number of data samples (i.e., a sample
32 group) have been collected for each magnetometer 12, as determined
33 during step 82, the data from each sample group are then summed and
34 averaged in step 84. The averaging process effectively removes the
35 fluctuations resulting from the periodic magnetic noise generated
36 by the use of a.c. power systems, which may be desirable if the
37 system 10 is not provided with a separate noise filter 29, as

1 described above. In one preferred embodiment, the arithmetic sum
2 of the data samples in each sample group is divided by the total
3 number of samples to yield the average for that sample group.
4 However, other averaging techniques are known and could be readily
5 substituted for the simple mathematical averaging technique just
6 described. Consequently, the present invention should not be
7 regarded as limited to any particular averaging technique. The
8 program flow then returns to step 54. See Figure 4.

9 Once the program flow reaches step 54, the system 14 may be
10 operated in one of two user-selectable "data collection" modes: A
11 "collect baseline data" mode or a "collect surveillance data" mode.
12 Step 54 monitors the appropriate input device (e.g., keyboard)
13 associated with the computer system 32 and awaits a command to enter
14 the appropriate mode, which may be implemented in the manner already
15 described, i.e., by keyboard entry or icon "click."

16 If the detection apparatus 10 is being operated for the first
17 time or if it is being operated at a new site or position, it will
18 usually be desirable to first operate the system 10 in the "baseline
19 data collection" mode in which data are collected from the
20 magnetometers 12, averaged, and stored as "baseline data" in step
21 56. However, in one preferred embodiment, the detection apparatus
22 10 is operated in the "baseline data collection" mode on a regular
23 basis (e.g., about once every 10 minutes or so, although other time
24 intervals could also be used) to ensure that the "baseline data" are
25 representative of the current ambient magnetic field B.

26 Regardless of when the detection apparatus 10 is operated in
27 the "baseline data collection" mode, the collected "baseline data"
28 are representative of the characteristics of the ambient or
29 background magnetic field, which may contain anomalies resulting
30 from the presence of periodic magnetic field fluctuations resulting
31 from nearby a.c. power transmission or devices. Such background
32 anomalies may also be the result of relatively massive ferromagnetic
33 materials located outside the sensing area 16. The collection of
34 the "baseline data" therefore provides a basis for comparing
35 magnetic anomalies that may be in the "surveillance data" against
36 those magnetic anomalies that are always present.

1 Once the "background data" have been collected and stored, the
2 program flow returns to step 50 and the metal detection apparatus
3 10 may be operated in the other "data collection" mode, i.e., the
4 "surveillance data collection" mode (steps 54-62). In the
5 "surveillance data collection" mode the output data signals 18 from
6 the magnetometers 12 are periodically sampled by the data
7 acquisition system 30 and fed into the computer system 32. These
8 data are referred to as "surveillance data." The "surveillance
9 data" are collected in exactly the same manner as the "background
10 data," i.e., during step 52 (Figures 4 and 5). Therefore, the
11 surveillance data collection process will not be described further.

12 Once the "surveillance data" have been collected, are
13 processed by the computer system 32 to remove the background noise
14 and, optionally, to determine whether any magnetic anomalies are
15 present that may be indicative of the presence within the sensing
16 area 16 of a ferromagnetic object or objects. These data are
17 referred to herein as "classified data." As a first step 58 in
18 processing the "surveillance data" to produce "classified data" the
19 computer system 32 first subtracts the "baseline data" from the
20 "surveillance data" to create "nulled" or "filtered surveillance
21 data." The "nulled" or "filtered surveillance data" are free of
22 those ambient magnetic anomalies that may be caused by materials and
23 devices surrounding the particular installation, e.g., electrical
24 equipment and/or massive ferromagnetic objects. Therefore, any
25 magnetic anomalies remaining in the "nulled" or "filtered
26 surveillance data" are likely the result of the presence of
27 ferromagnetic objects within the actual sensing area 16.

28 In one preferred embodiment, the "nulled" or "filtered
29 surveillance data" are quantified and presented on the display
30 device 20 as a two dimensional plot of magnetic field gradient (∇)
31 vs. vertical position (V) within the sensing area 16. See Figures
32 6A-F. Alternatively, the "filtered surveillance data" may be
33 further processed to produce "classified data" which may then be
34 presented on the display device 20 in a form substantially as shown
35 in Figure 8.

36 However, before proceeding with a detailed description of the
37 various methods used to classify the "nulled" or "filtered

1 surveillance data," it is important to recognize that the "filtered
2 surveillance data" may be reflective of either a dipole response or
3 a monopole response depending on the characteristics of the detected
4 ferromagnetic object. The particular methods used to classify the
5 surveillance data differ depending on whether a dipole response or
6 a monopole response is detected.

7 A "dipole" response is shown in Figures 6A-F and may be
8 produced by a relatively large or elongate ferromagnetic object.
9 Briefly, such a dipole response results from the fact that the two
10 magnetic poles (i.e., the north and south poles) induced in the
11 object by the ambient magnetic field B are located relatively far
12 apart, generally within the resolution of the sensor array 40. In
13 contrast, a more compact, generally less elongate object will
14 develop magnetic poles that are closer together, thus less readily
15 resolved by the detector array 40. Such a response is referred to
16 herein as a "monopole" response and is shown in Figures 7A-F. A
17 detailed discussion of the two types of responses follows.

18 Figures 6A-F are indicative of a dipole response. In each
19 figure, the magnetic field gradient ∇ (in units of nanotesla/meter)
20 is plotted along the lower abscissa 97 (the lower horizontal axis),
21 while vertical position is plotted along the ordinate 98 (the
22 vertical axis). Also, for the purpose of correlating the horizontal
23 position of the sample ferromagnetic object 86 with respect to the
24 two rows 22, 24 of sensors, the horizontal position of the object
25 86 may be plotted along the upper horizontal axis 99.

26 Figures 6A-F also show the magnetic field gradient ∇
27 corresponding to several different vertical positions of a sample
28 ferromagnetic object 86 producing a dipole response, in this case
29 a Browning 9mm semiautomatic pistol. Thus, in Figure 6A the pistol
30 86 (represented schematically in Figures 6A-F) is located about 6
31 feet above the floor; in Figure 6B, 5 feet above the floor, and so
32 on through Figure 6F, wherein the pistol 86 is located approximately
33 1 foot above the floor. In each case, the pistol 86 is located
34 about 9 inches to the right of the left column 22 of sensors 12, as
35 indicated by reference to the upper horizontal axis 99. Curve 88
36 represents the gradient ∇ of the magnetic field B detected by the
37 sensors 12 in row 22 (i.e., the left-hand sensors 12), whereas curve

1 90 represents the gradient detected by the sensors 12 in the right
2 hand row 24 of sensors 12. See also Figures 1 and 2.

3 As can be seen from the curves 88, 90 in each of the Figures
4 6A-F, the presence of the pistol 86 in the sensing area 16 produces
5 a significant change in the magnetic gradient ∇ . Since, in each
6 case, the gun 86 is located nearer to the left-hand row 22 of
7 sensors 12 than the right-hand row 24, the most significant change
8 in the magnetic gradient ∇ is detected by the left-hand row 22 of
9 sensors 12 (i.e., curve 88), although there is some variation
10 detected by the right-hand row of sensors 24 (i.e., curve 90). A
11 significant feature of the magnetic gradient ∇ (curves 88, 90)
12 produced by an object having a dipole response characteristic is
13 that the magnetic field gradient ∇ changes sign (i.e., from a
14 negative (-) gradient or value to a positive (+) gradient or value).
15 Put in other words, each curve 88, 90 may include one or two
16 relative maximum (i.e., positive magnetic gradient) and/or minimum
17 (i.e., negative magnetic gradient) points, e.g., points 92, as well
18 as an inflection point 61, as best seen in Figure 6C.

19 Qualitatively, the curves 88, 90 and relative maximum and/or
20 minimum points 92 are indicative of magnetic field anomalies that
21 may be caused by the presence of ferromagnetic materials located
22 within the sensing area 16, such as the pistol 86. Quantitatively,
23 the curves 88, 90 and the points 92 may be evaluated by the data
24 collection and classification program 46 to reach a determination
25 as to the likelihood that the detected ferromagnetic material
26 contains sufficient mass to warrant further investigation.
27 Accordingly, the data collection and classification program 46 may
28 include in the step 60 a classification process wherein the
29 "filtered surveillance data" are classified to produce "classified
30 data" indicative of the relative mass and/or location of the
31 detected ferromagnetic object. The "classified data" would then be
32 presented on the display device 20 as a plurality of highlights 96
33 indicating the relative mass and likely position of the detected
34 ferromagnetic object.

35 For an object producing a dipole response characteristic, such
36 as those shown in Figures 6A-F, the approximate vertical position
37 of the ferromagnetic object, e.g., the pistol 86, may be inferred

1 from the location of the inflection point 61. For example,
2 referring to Figure 6C, the corresponding vertical position of the
3 inflection point 61 is approximately 4 feet above the floor, which
4 corresponds to the approximate vertical position of the pistol 86.
5 The location of the inflection point 61 may be defined
6 mathematically as that point where the partial second derivative of
7 the vertical position V (ordinate 98) with respect to the magnetic
8 field gradient ∇ is zero. Stated mathematically, point 61 is
9 defined as that point where:

$$\frac{\partial^2 \nabla}{\partial V^2} = 0$$

10 Therefore, the approximate vertical position of an object 86
11 exhibiting a dipole response may be determined by finding the
12 vertical location that corresponds to the inflection point 61.

13 The approximate horizontal position of a ferromagnetic object
14 (e.g., pistol 86) producing a dipole response characteristic may be
15 inferred from the differences between the two curves at either the
16 relative maximum or minimum points 92. For example, again referring
17 to the example represented by Figure 6C, the greater the difference
18 of magnetic gradient ∇ between the point 92 on curve 88 and a
19 corresponding point 93 on curve 90, the closer the ferromagnetic
20 object is located to the row of magnetometers represented by that
21 curve, e.g., in this case the left-hand row 22. If, for example,
22 the detected ferromagnetic object is located in the center of the
23 doorway 42, substantially midway between the two rows 22, 24, then
24 the difference between the magnetic gradient sensed by the two rows
25 of sensors, will be rather small, close to zero. Similarly, if the
26 object were positioned close to the right hand-row 24, then the
27 curve 90 would contain the largest magnetic gradient variation,
28 therefore indicating that the object is closer to the magnetometers
29 12 in the right-hand row 24.

30 The mass of the detected ferromagnetic object having a dipole
31 response characteristic may be estimated by integrating the magnetic
32 field gradient ∇ , i.e., by calculating the area bounded by the curves
33 (e.g., 88, 90) and the vertical line corresponding to zero (0)
34 magnetic gradient. For example, still referring to Figure 6C, the

1 "integrated magnetic density" obtained by integrating curve 88
2 corresponds to the shaded areas bounded by the curve 88 and the zero
3 point of the horizontal axis (i.e., zero magnetic gradient ∇).
4 Generally speaking, large integrated magnetic densities are
5 indicative of large field gradients, which are in turn indicative
6 of large (i.e., massive) ferromagnetic objects. Therefore, large
7 integrated magnetic densities are generally indicative of relatively
8 massive ferromagnetic objects.

9 Still other information about the object 86 may be gleaned
10 from the "integrated magnetic density." For example, by comparing
11 the "integrated magnetic density" obtained from both sets of sensors
12 (i.e., curves 88 and 90), a determination (or verification) can be
13 made as to the relative horizontal position of the object 86. That
14 is, if the integrated magnetic density is large for the left-hand
15 sensors and relatively small for the right hand sensors, then the
16 object is located closer to the left-hand sensors. Similarly, if
17 the integrated magnetic density values are approximately equal for
18 both sets of sensors, then the object 86 is located near the mid-
19 point between the two rows 22, 24 of sensors 12.

20 As was mentioned above, smaller, generally more compact
21 ferromagnetic objects may produce a monopole response
22 characteristic, as best seen in Figures 7A-F. If this type of
23 monopole response is detected, then the system 14 classifies the
24 "nulled" or "filtered surveillance data" as follows.

25 Referring now to Figures 7A-F, a relatively compact object,
26 in this case a Walther PPK 9mm semi-automatic pistol, produces a
27 monopole response 88', i.e., a response wherein the magnetic
28 gradient ∇ generally does not change sign. For example, the
29 magnetic gradient ∇ shown in Figures 7A-F generally remains
30 negative. However, the magnetic gradient could also be positive.
31 Since the magnetic gradient ∇ does not change sign, there is no
32 inflection point, or if there is one, it is difficult to detect.
33 Accordingly, the approximate vertical position of the object 86' is
34 determined by locating a peak 92' on the monopole response curve
35 88'. The approximate horizontal position of the object 86' may be
36 determined by evaluating the magnitude of the peak 92'.
37 Alternatively, the horizontal position may be determined or

1 confirmed by calculating the value of the integrated magnetic
2 gradient (i.e., the shaded area between the curve 88' and the
3 vertical line corresponding to zero magnetic gradient, Figure 7B),
4 as was the case for an object having a dipole response
5 characteristic. The relative size (i.e., mass) of the ferromagnetic
6 object may be determined by integrating the magnetic gradient ∇ , as
7 was also described above.

8 After determining the approximate horizontal and vertical
9 locations of the detected object or objects, as well as making some
10 determination as to its mass (by integrating the magnetic gradient
11 curve), the resulting data can then be presented on the display 20.
12 Referring now to Figure 8, one such display 20 could include a
13 computer generated picture of a doorway 42 and associated opening
14 44. The computer system 32 could also generate a silhouette 94 of
15 the person in the sensing area 16 with the probable locations and
16 relative sizes of the detected ferromagnetic objects indicated by
17 highlights 96. Alternatively the display may include a video "snap
18 shot" of the doorway and person obtained from a video camera (not
19 shown) associated with a video surveillance system (also not shown)
20 and positioned to view the doorway.

21 The sensor array 40 may take on any of a wide variety of
22 configurations depending on the desired application. For example,
23 another embodiment of a sensor array 140 is shown in Figure 9 as it
24 could be configured to comprise a portable sensor array 140.
25 Essentially, the portable sensor array 140 is similar to the sensor
26 array 40 shown in Figures 1 and 2 and could comprise two panels 122,
27 124, each of which contains a plurality of sensors or magnetometers
28 112, one of which is shown in Figure 9. The magnetometers 112 are
29 mounted within the panels 122, 124 in generally spaced-apart
30 relation. Each panel 122, 124 is oriented so that the magnetometers
31 112 face one another in the manner shown in Figures 1 and 2. The
32 panels 122, 124 may be fabricated from any of a wide variety of non-
33 ferromagnetic materials, such as wood or aluminum, so as not to
34 interfere with the detection capability of the sensors 112. A
35 suitable conduit 178 may be provided as a convenient means for
36 routing the various wires (not shown) required to connect the
37 magnetometers 112 to the power supply (not shown) and signal

1 processing system (also not shown) which may be located at a remote
2 location. The power supply and signal processing system may be
3 substantially identical to the power supply 46 and signal processing
4 system 14 shown and described above.

5 Yet another embodiment 240 of the sensor array is shown in
6 Figure 10 as it could be incorporated into a doorway 242. This
7 embodiment of the sensor array 240 differs from the first embodiment
8 40 shown in Figures 1 and 2 in that it comprises only a single row
9 222 of magnetometers 212. Each of the magnetometers 121 may be
10 connected to a remotely located power supply and signal processing
11 system (not shown) by a suitable conduit 278. As was the case for
12 the sensor array 40, the doorway 242 housing the sensor array 240
13 should be constructed from non-ferromagnetic materials, such as wood
14 or aluminum, for maximum sensitivity and effectiveness.

15 Generally speaking, the sensor array 240 is not as sensitive
16 as the sensor arrays having two opposed rows of magnetometers, e.g.,
17 sensor arrays 40 and 140, particularly if the ferromagnetic object
18 is located at the far end of the sensing area 216, e.g., near the
19 right-hand side 241 of doorway 242. However, sensor array 240 has
20 the advantage of requiring fewer magnetometers 12, and may be
21 suitable in those instances involving relatively narrow doorways or
22 in well-shielded environments wherein magnetic anomalies resulting
23 from the presence of ferromagnetic materials would be easy to
24 detect, even at the far right end of the sensing area 216.

25 Still other configurations for the sensor array are possible.
26 For example, a sensor array 340 is shown in Figure 11 as it could
27 be incorporated into a doorway 342. As was the case for the first
28 sensor array 40, the sensor array 340 comprises two rows 322, 324
29 of sensors 312, except that the rows 322, 324 are horizontally
30 oriented to comprise an upper row 322 and a lower row 324. As was
31 the case for the sensor arrays 40 and 240, the doorway 342
32 incorporating the sensor array 340 should be made from non-
33 ferromagnetic materials.

34 This completes the detailed description of the preferred
35 embodiments of the advanced metal detection apparatus according to
36 the present invention. While a number of specific components were
37 described above for the preferred embodiments of this invention,

1 persons skilled in this art will readily recognize that other
2 substitute components or combinations of components may be available
3 now or in the future to accomplish comparable functions to the
4 apparatus described herein. Accordingly, it is contemplated that
5 the inventive concepts herein described may be variously otherwise
6 embodied and it is intended that the appended claims be construed
7 to include alternative embodiments of the invention except insofar
8 as limited by the prior art.

WE CLAIM:

1 1. Apparatus for detecting a ferromagnetic object,
2 comprising:

3 a plurality of magnetometers arranged along a
4 first row for sensing a magnetic field within a sensing
5 area, each of said plurality of magnetometers producing
6 an output signal relating to the detected magnetic
7 field; and

8 signal processing apparatus connected to each of
9 said plurality of magnetometers and responsive to the
10 output signals produced thereby for generating a human-
11 readable display indicative of the presence of the
12 ferromagnetic object within the sensing area.

1 2. The apparatus of claim 1, wherein said plurality of
2 magnetometers are arranged along a first row and a second row, the
3 first and second rows being positioned in spaced-apart, generally
4 opposed relation so that the sensing area defined by said plurality
5 of magnetometers comprises a generally planar area extending between
6 the first and second rows.

1 3. The apparatus of claim 2, wherein the first and second
2 rows are generally vertically oriented, with the second row being
3 positioned a lateral distance from the first row so that the sensing
4 area comprises a generally vertically oriented plane.

1 4. The apparatus of claim 3, wherein the first and second
2 rows are generally horizontally oriented, with the second row being
3 positioned a vertical distance from the first row so that the
4 sensing area comprises a generally vertically oriented plane.

1 5. The apparatus of claim 4, wherein each of said plurality
2 of magnetometers comprises a magnetic gradiometer and wherein each
3 of the output signals produced thereby is related to a gradient of
4 the magnetic field.

1 6. The apparatus of claim 5, wherein said signal processing
2 apparatus comprises:

3 a data acquisition system connected to each of
4 said plurality of magnetometers for collecting a
5 predetermined number of data samples from each of said
6 plurality of magnetometers and for producing a data
7 sample output;

8 a computer system connected to said data
9 acquisition system for receiving the data sample output
10 from said data acquisition system and for producing
11 computer output data relating to the presence of the
12 ferromagnetic object; and

13 a display system connected to said computer
14 system and responsive to the computer output data
15 relating to the presence of the ferromagnetic object
16 for displaying a human readable signal relating to the
17 computer output data.

1 7. The apparatus of claim 6, wherein said plurality of
2 magnetometers comprising the first row is eight and wherein said
3 plurality of magnetometers comprising the second row is eight.

1 8. The apparatus of claim 7, wherein each of said plurality
2 of magnetometers comprising the first and second rows is
3 substantially evenly spaced from the others of said magnetometers
4 positioned in that row.

1 9. The apparatus of claim 8, wherein the distance between
2 adjacent magnetometers in each of the first and second rows is in
3 the range of about eight (8) to ten (10) inches.

1 10. The apparatus of claim 1, wherein each of said plurality
2 of magnetometers comprises a fluxgate gradiometer.

1 11. A method for detecting a presence of a ferromagnetic
2 object within a sensing area, comprising the steps of:
3 collecting baseline data signals from a
4 magnetometer when the sensing area is devoid of a
5 ferromagnetic object to be detected;
6 collecting surveillance data signals from said
7 magnetometer;
8 comparing said surveillance data with said
9 baseline data to create filtered surveillance data,
10 said filtered surveillance data being indicative of the
11 presence and absence of the ferromagnetic object within
12 the sensing area; and
13 displaying said filtered surveillance data on a
14 display device.

1 12. The method of claim 11, further comprising the step of
2 classifying said filtered surveillance data to produce classified
3 data, said classified data being indicative of a detected location
4 and a detected mass of the ferromagnetic object.

1 13. The method of claim 11, further comprising the step of
2 storing said baseline data signals before comparing them with said
3 surveillance data signals.

1 14. Apparatus for detecting a ferromagnetic object,
2 comprising:

3 a first magnetometer for detecting a magnetic
4 field and for producing a first data signal relating to
5 the detected magnetic field;

6 a second magnetometer for detecting the magnetic
7 field and for producing a second data signal relating
8 to the detected magnetic field, said second
9 magnetometer being positioned adjacent said first
10 magnetometer so that said first and second
11 magnetometers define a generally planar sensing area;
12 and

13 signal processing apparatus connected to said
14 first magnetometer and to said second magnetometer and
15 responsive to the first and second data signals
16 produced thereby for generating an output data signal
17 indicative of the presence of the ferromagnetic object
18 in the sensing area.

1 15. The apparatus of claim 14, wherein said first and second
2 magnetometers comprise respective first and second magnetic
3 gradiometers and wherein said first and second data signals are
4 related to strength gradients of the magnetic field.

1 16. The apparatus of claim 15, wherein said first and second
2 magnetic gradiometers are positioned in generally spaced-apart
3 opposed relation so that the sensing area comprises a generally
4 vertically oriented plane.

1 17. A method for minimizing an effect of a periodic noise
2 signal contained on a variable data signal, the periodic noise
3 signal having a predetermined frequency and period, comprising the
4 steps of:

5 collecting a predetermined number of samples of
6 the variable data signal over a sample period
7 commensurate in length to a predetermined number of
8 periods of the noise signal, each of said predetermined

9 number of samples having associated with it a data
10 value;

11 adding together the data values of each of said
12 predetermined number of samples to create a sum total
13 data value; and

14 dividing the sum total data value by the
15 predetermined number of samples to create an average
16 datum.

1 18. The method of claim 17, where the predetermined number
2 of samples is 51 and wherein the predetermined number of periods of
3 the noise signal is three.

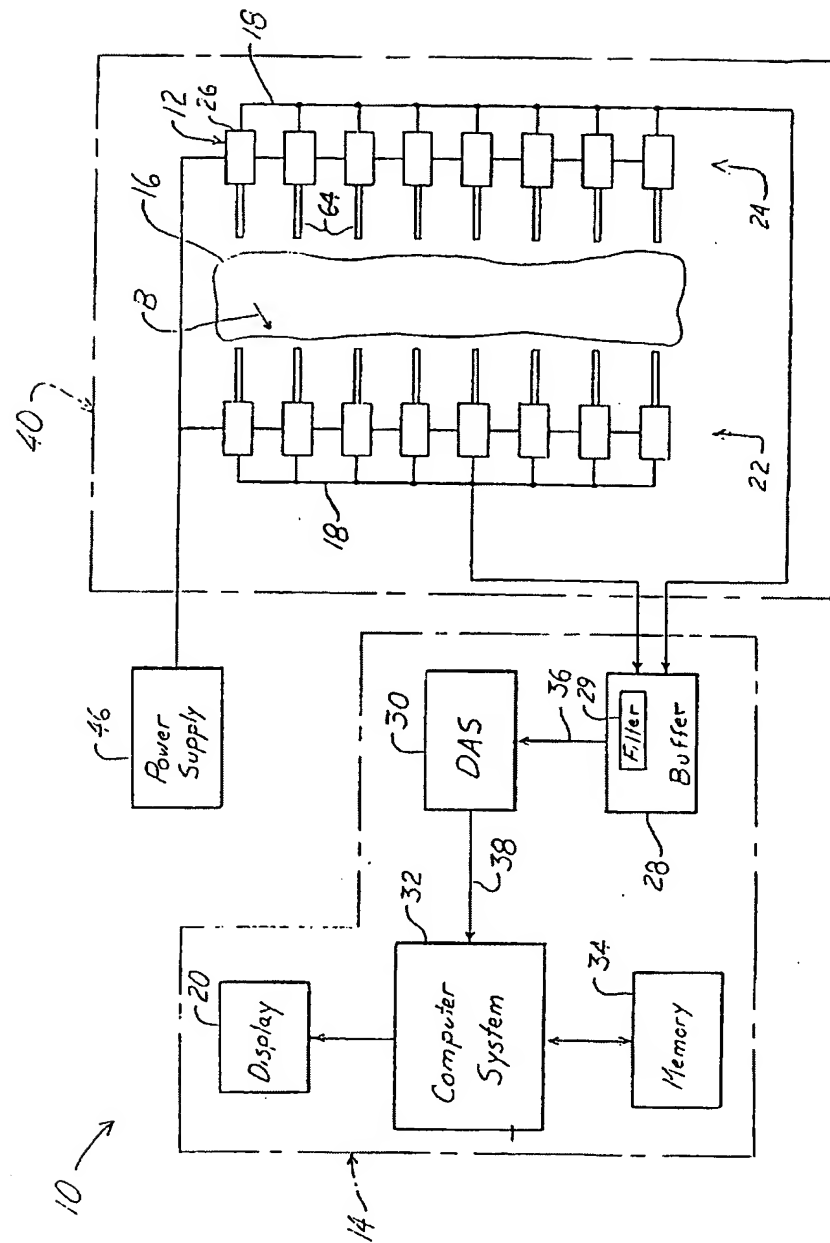


Fig. 1

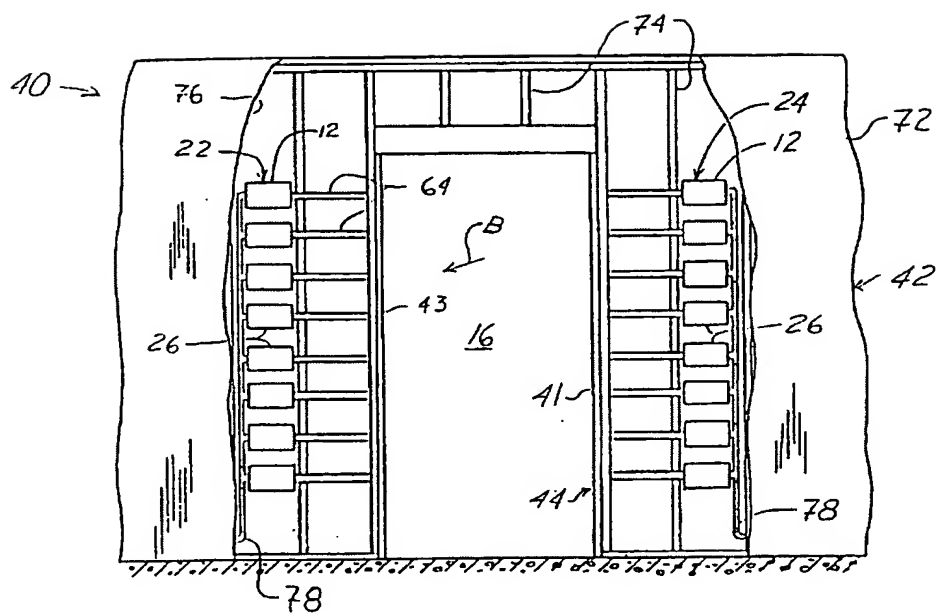


Fig. 2

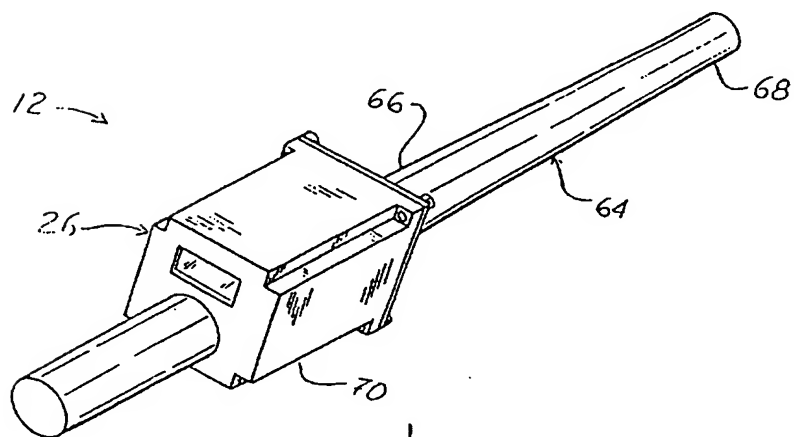


Fig. 3

3/10

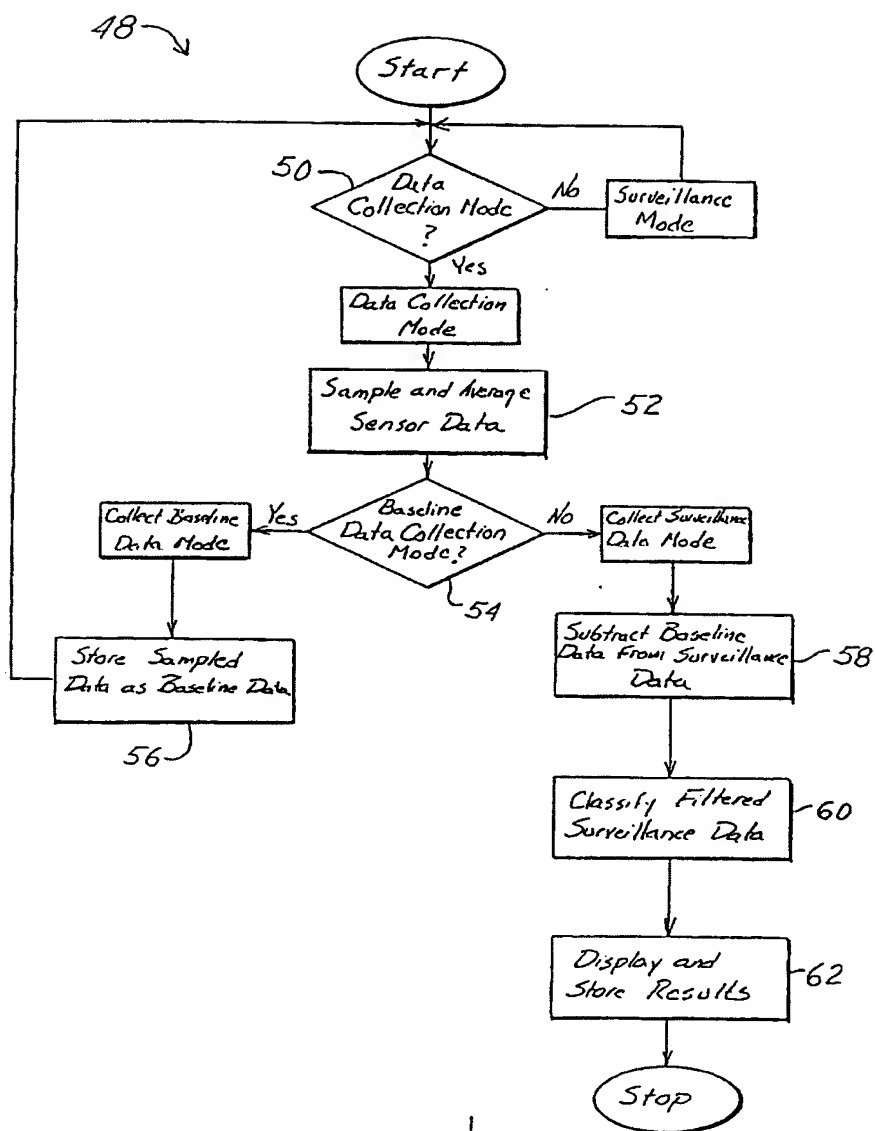


Fig. 4

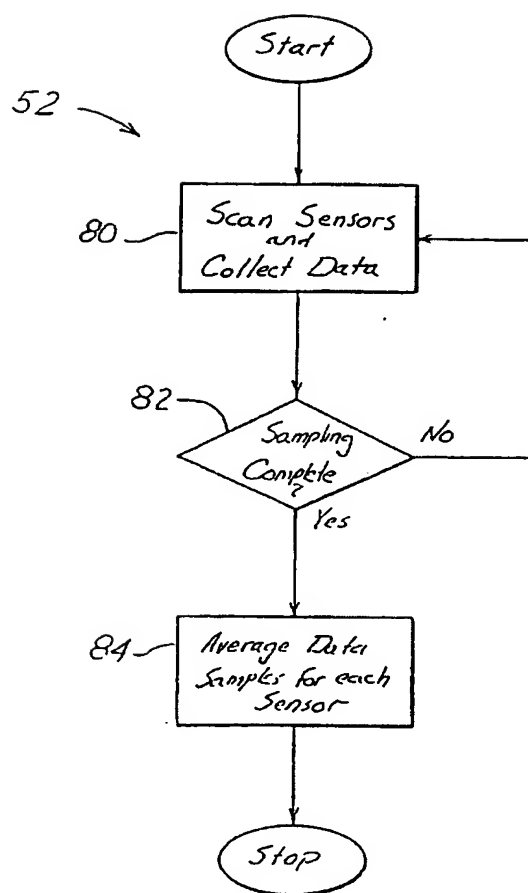


Fig. 5

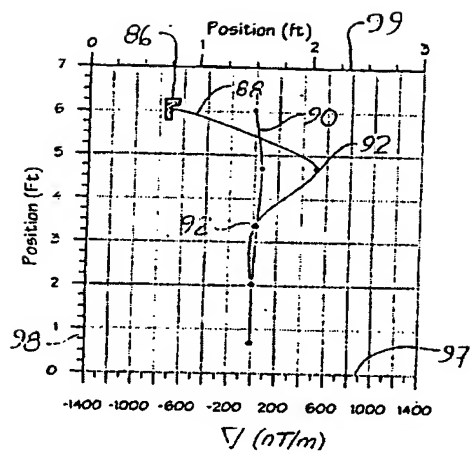


Fig. 6A

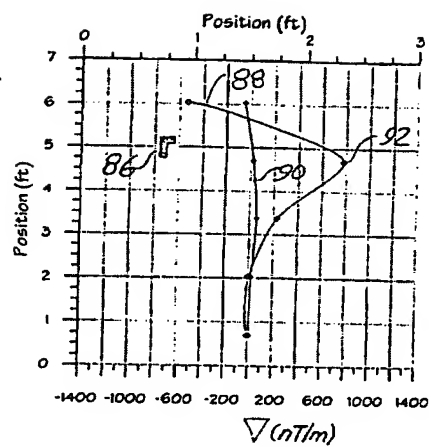


Fig. 6B

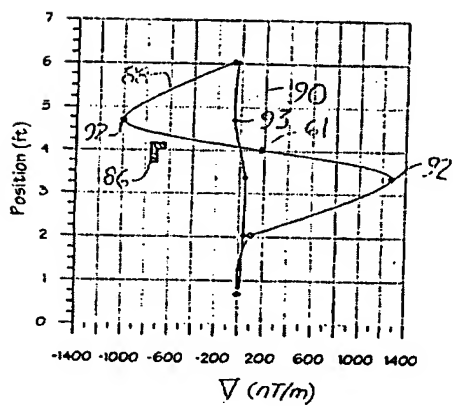


Fig. 6C

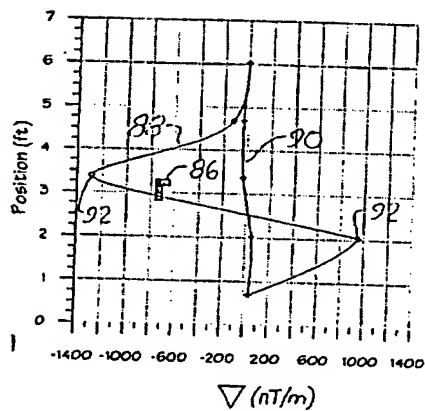


Fig. 6D

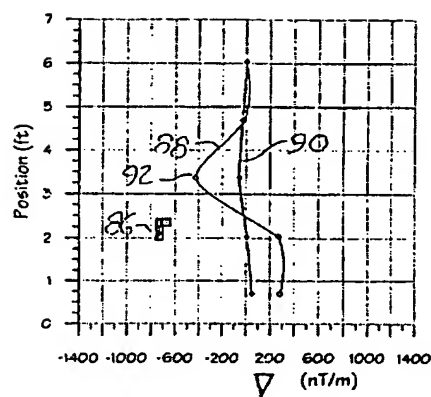


Fig. 6E

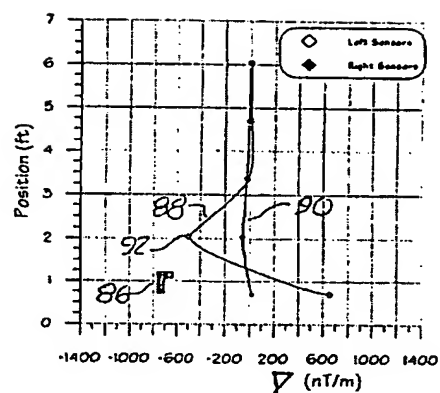


Fig. 6F

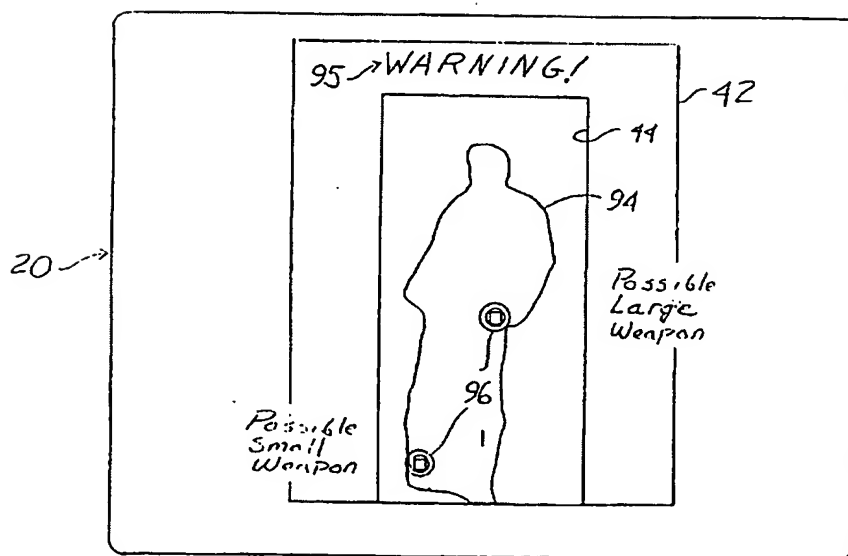


Fig. 8

.7/10

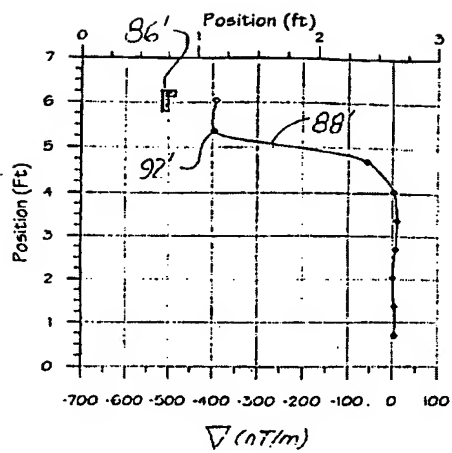


Fig. 7A

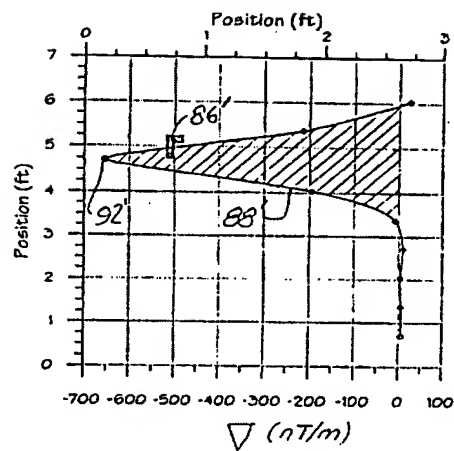


Fig. 7B

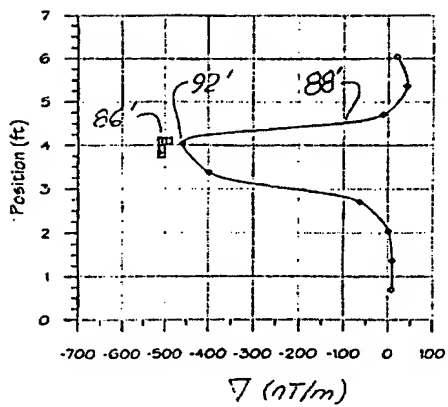


Fig. 7C

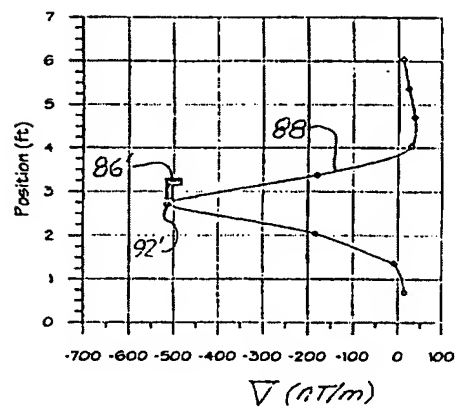


Fig. 7D

8/10

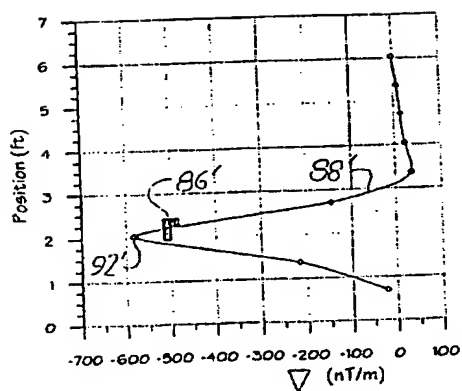


Fig. 7E

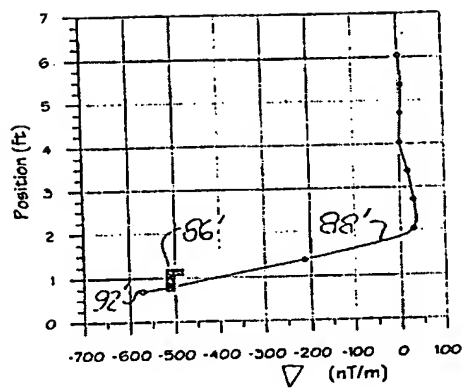


Fig. 7F

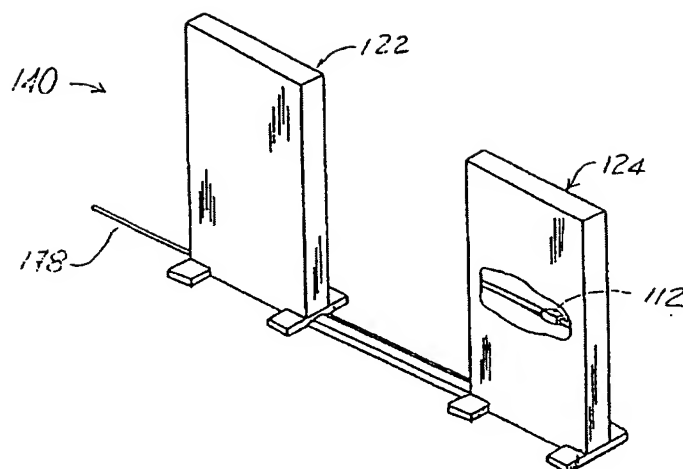


Fig. 9

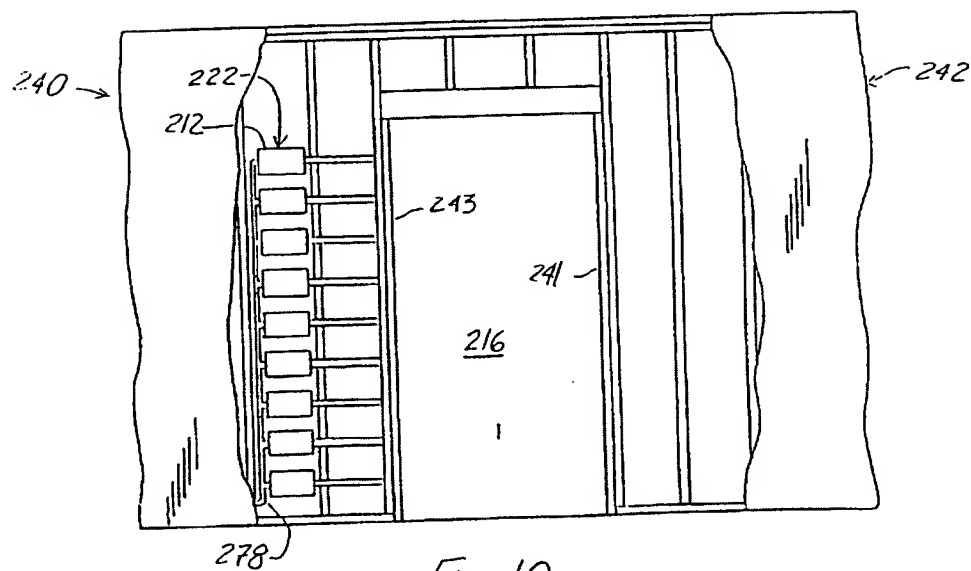


Fig. 10

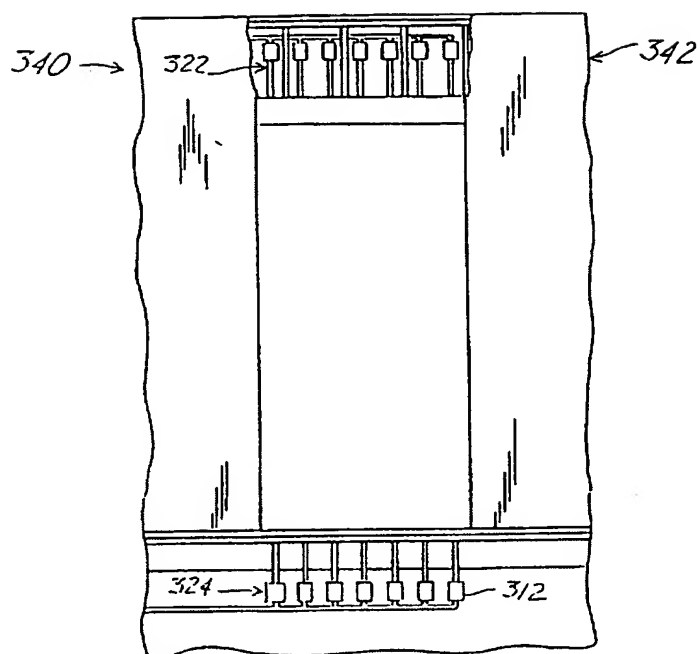


Fig. 11

THIS PAGE BLANK (USPTO)

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☐ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☒ FADED TEXT OR DRAWING
- ☒ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.

THIS PAGE BLANK (USPTO)